The role of constituent index relationships for CSO treatment process decisions in the highly urbanized liguori catchment of cosenza - Italy

Utilisation d'indices de pollution pour choisir les procédés de traitement des rejets urbains de temps se pluie dans un bassin versant fortement urbanisè : Liguori de Cosenza - Italie

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RESUME

Dans les bassins urbains, les différences entre les caractéristiques des solides et de la demande en oxygène ont comme conséquence l'efficacité variable du traitement par des opérations physiques unitaires et des processus biologiques unitaires. Les charges organiques plus élevées pendant l'écoulement par temps sec sont plus favorables aux processus biologiques unitaires tandis que les charges inorganiques plus élevées produites en grande partie par les constituants urbains de temps de pluie et les écoulements beaucoup plus grands peuvent plus efficacement être traités ou conditionnés par des opérations physiques unitaires comprenant des contrôles hydrologiques intégrés. Cette étude examine les rapports parmi la demande chimique en oxygène totaleCODt, la demande chimique en oxygène dissous CODd, la demande chimique en oxygène des particules CODp et les solides, mesurés en tant que solides totaux en suspension TSS. Les résultats fournissent un index pour le choix et l'optimisation des opérations de traitement des charges de CSO.

ABSTRACT

In urbanizing catchments the variability of particulate matter (solids) and oxygen demanding constituents of wet weather and dry weather characteristics result in variable treatment effectiveness from physical unit operations and biological unit processes. Higher organic concentration during dry weather flow are more amenable to biological unit processes while the higher inorganic loads generated largely by urban wet weather constituents and much larger flows can be more effectively treated or conditioned by physical unit operations including ideally preceded by hydrologic controls. This study examines the relationships among total chemical oxygen demand (COD)t, dissolved chemical oxygen demand (COD)d, particulate chemical oxygen demand (COD)p and solids, measured as total suspended solids (TSS). Results also provide an index for selection and optimization of treatment operations for combined sewer overflow (CSO) loads.

KEYWORDS

Combined sewer overflows (CSO), Flow, COD, TSS, Wet Weather, Treatment.

1 INTRODUCTION

It has been well-documented that incrementally improving wastewater treatment plant (WWTP) processes in conjunction with additional CSO treatment can be effective means of reducing pollutant loads to receiving waters.

Nevertheless, finding a satisfactory solution to these systems for mitigating the effects of discharged pollutant concentration is a formidable task. Specifically, the complexity of the problem is due to the variability of CSOs; including frequency of occurrence, constituent concentration and flow rate.

Therefore, an optimized treatment for control of CSOs must be amenable to variable hydraulic rates and pollutant concentrations in order to function appropriately in dry and wet weather and must also be flexible to variable site-specific conditions.

Initially, when formulating potential control strategies a preliminary screening, conducted to establish the partitioning and distribution of pollutant loads, is required. Typically, investigated parameters are particulates and chemical oxygen demand, as they are significant loads in urban runoff. In particular, particulates can be measured by total suspended solids (TSS) that represent one index for evaluating wet weather pollution in CSOs and stormwater discharges in urban areas (Sansalone et al., 1998). In order to achieve optimal treatment using WWTP and CSO operational objectives, the governing design guidelines must be formed once pollutant loadings have been fully quantified and the relationships among parameters such as TSS, total COD as well as dissolved/particulate fractions of COD have been understood. Consequently, with these results any specific potential treatment strategies can be proposed.

In this research study, the fundamental objectives were threefold and directed together toward examining relationships between COD fractions and TSS. The first aim was to examine the water quality characteristics in dry weather and wet weather flows. The second objective involved the variation in the set of experimental data of the index $f_D=COD_d/COD_t$ and evaluate implications with regards to treatment design. Finally, the third goal was to investigate the correlations between COD_t, COD_p and TSS. The results provide important indicators in order to optimize treatment unit operations and processes (UOPs).

1.1 Background

Conventional wastewater treatment consists of a combination of physical operations and biological (and some chemical) processes to separate solids, convert (generally oxidize) organic matter and separate nutrients from wastewater. UOPs are organized in a process orientation to provide various levels of treatment generally classified as primary, secondary (without or with nutrient removal), and advanced (or tertiary) treatment. In primary treatment, a physical operation, usually sedimentation; is designed to remove organic and inorganic solids by the physical processes of sedimentation and flotation. In secondary treatment, biological (occasionally chemical) processes are used to convert most of the organic matter (Metcalf and Eddy 1997). Such physical unit operations and biological unit processes perform differently under various weather conditions. In particular, during storm events solids loads of suspended, settleable and sediment solids increase as runoff waters wash off dry deposition inventory built up on the catchment surfaces during previous dry weather. In this case, the sewerage systems deliver large amounts of inorganic loads, whose removal is achieved significantly by means of physical unit operations. Conversely, during dry weather flows experimental data demonstrates that organic concentrations become higher. These organic matter concentrations can be converted (oxidized) by biological unit processes.

The researchers hypothesized that there should be a relationship between TSS and COD in an urbanizing catchments. In this study, researchers have monitored water quality characteristics at Italian experimental catchments in relation to indices such as TSS and COD, used to predict solids and organic matter loadings respectively. These researchers have investigated the potential correlations between TSS and COD. In general, the relationship between TSS and COD is reasonably linear.

Since 1994 the Soil Conservation Department of the University of Calabria has been carrying out a monitoring plan on storm water runoff quality from the Liguori catchment in Calabria. This specific study is a component of a larger long-term study to carry out research and analyses to examine the impacts of storm events on the receiving water environment. Previous results indicated that while in the receiving water body, the Crati River, the water quality upstream of the CSO structure is acceptable according the EU Directive 271/91. However, downstream of the CSO structure the pollutant loads from the CSO discharges are much higher, with a commensurate increase of pollutant concentrations and degradation of oxygen levels in the river (Calomino et al. 2004). These results have demonstrated that CSO treatment is required.

2 METHODS

2.1 Description of the catchment

All data presented in this paper were collected from the experimental catchment and facility located in the Liguori channel in Cosenza, Italy. The Liguori channel, originally a natural water body, has been altered due to increasing urbanization. The channel has now become an urban conduit which is part of a combined drainage network. The urban experimental catchment is totally 414 hectares wide, out of which 202 hectares are pervious, reasonably undisturbed and covered by vegetation, while the rest of the catchment consists of a paved area from which the channel receives wet weather flow. In the extended densely populated urban Liguori catchment, existing buildings are almost exclusively used for residential housing and minor commercial and artisan enterprises. There are no known industrial activities in the catchment. The total number of residents in the catchment is about 50,000.

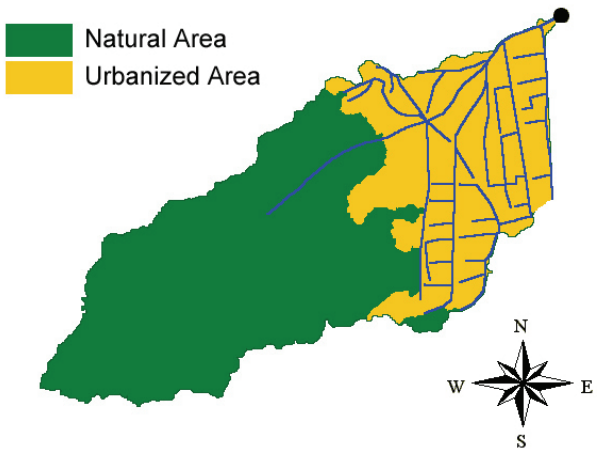

Figure 1 : Experimental urbanized Liguori catchment of Cosenza

Further details on the physical characteristics of the basin and the drainage system are reported in other publications (Piro P. 2006). While dry weather flows and wet weather flows that do not exceed treatment capacity are sent to the regional wastewater treatment plant (WWTP), exceedence resulted in untreated CSO discharges to the Crati River. More information about the untreated CSO features can be found in other papers (Calomino et al, 2003, 2004).

2.1.1 Quantity and Quality Data Collection

A meteorological and sampling station has been installed in the lower reach of the sewer network before flows enter the treatment plant. The station is basically equipped with an ultrasonic sensor, for continuous flow monitoring, and a tipping bucket rain-gauge. More specifically, for each event one-minute rainfall data and one-minute runoff data, obtained from continuous level measurements, are recorded in a data logger.

In order to examine the differences between inorganic and organic loads under both dry and wet weather conditions, sampling was conducted during two respective sets of conditions. In particular, it is necessary to emphasize that a storm event for this study was defined as a rain event that is preceded and followed by al least 10 h of dry weather conditions. All samples were taken manually as discrete samples. Samples were collected in replicate at each time intervals in 500mL wide mouth polypropylene bottles from the time of the start of observable rainfall at the site to the cessation of runoff for each particular event. As regards sampling intervals samples were collected at consistent 15 min intervals throughout each event.

Dry weather sampling was useful in order to establish background pollutant concentrations and the data provided a basis of comparison for storm event samples to better assess the extent of the pollution that is contributed by urban runoff. 27 representative dry weather samples were collected based on sampling at consistent 15 min intervals.

2.1.2 Water Quality Analysis

Immediately following each event, samples were transported to the laboratory within one hour for water quality analysis or, at most, within 12 hours of collection, with the samples refrigerated at 0°C for the interim.

As constituents for water quality, laboratory analyses of wastewater samples were performed considering the following chemical-physical parameters: total suspended solids TSS and chemical oxygen demand COD between the particulate and dissolved phases. Samples were fractionated between the total and dissolved phases immediately upon return to the laboratory for COD analysis on the respective phases. Suspended solids concentration was analyzed for each sample according to the 2540D protocol developed by APHA 1998. The COD determinations were carried out using both Standards methods 5220B (APHA 1998). The dissolved phase COD is represented by that material that passes through a 0.45-μm membrane filter, while the particulate fraction was directly inferred from the product of the result of this/such filtration analysis. Finally, the concentrations of COD_d and COD_t measured, as stated above, were used to calculate COD_p. The relative concentration of the constituents in the dissolved phase not only has significant implications for fate and transport of the constituents in runoff, but also is indicative of the bioavailability of the constituents in the receiving waters. The dissolved fraction is defined as follows:

$$f_d = \frac{COD_d}{COD_t}$$

Obviously, values of f_d greater than 0.5 indicate a higher affinity for the dissolved phase as opposed to the particulate phase. The magnitude of this phase distribution has fundamental implications, when considering primary-constituent-removal mechanisms in the treatment design. These f_d values are also indicative of the fate- and transport-control mechanisms, which govern the relative magnitude of the phase distribution of such constituents (Sansalone et al., 2001).

3 RESULTS

A total of n. 9 observations were characterized during the course of this study. Results show that values of COD and TSS are within the range of existing published values. In particular, COD concentrations range from 126 to 315 mg/l, while TSS varies from 30 to 286 mg/l. In addition, considerable hydrological characteristics associated with mean concentration of particulate and organic matter for all observations were summarized in Table n.1. Specifically, the emphasis was placed on the fact that TSS concentrations during wet weather are higher than that during dry weather. In fact, as well documented, the wet weather flow causes an increase of COD and TSS due to the wash-off from impervious surfaces and to sediments accumulated during dry weather in sewers.

Samples	Q_{max} [m^3/sec]	i_{avg} [mm/h]	h_{tot} [mm]	COD_t [mg/l]	COD_d [mg/l]	TSS [mg/l]	f_d
07/07/2006	0.5	1.9	2.0	233	92	128	0,39
12/07/2006	3.7	4.6	3.8	244	79	217	0,33
24/07/2006	0.4	0.0	0.0	285	109	95	0,38
25/07/2006	0.3	0.0	0.0	193	76	71	0,39
26/07/2006	0.3	0.0	0.0	225	74	108	0,33
27/07/2006	0.4	0.0	0.0	271	87	125	0,32
27/07/2006	6.6	10	10.2	187	57	150	0,31
28/07/2006	0.3	0.0	0.0	205	85	70	0,41
02/08/2006	0.3	0.0	0.0	211	65	81	0,31

Table 1 : Hydrological characteristics and mean concentrations of particulate and organic matter measured for each observation in experimental urbanized Liguori catchment of Cosenza

The correlations between the previously investigated water-quality parameters were found. In particular, the COD_t was plotted as a function of TSS readings from all samplings. In addition, the plotting has been performed for the wet and dry weather observations in order to examine the different characteristics of wet weather and dry weather flow.

The following Figure 2 shows some relevant results. Primarily the different behaviour between wet and dry weather gives a different relationship between COD versus TSS; this observation confirms that inorganic loads generated largely by urban wet weather constituents are higher than that during dry weather, while organic loadings exhibit similar concentration values during dry and wet weather flow.

Secondly the better fitting obtained for TSS versus COD_p relationship shows the importance of considering such relationship for the best management practices.

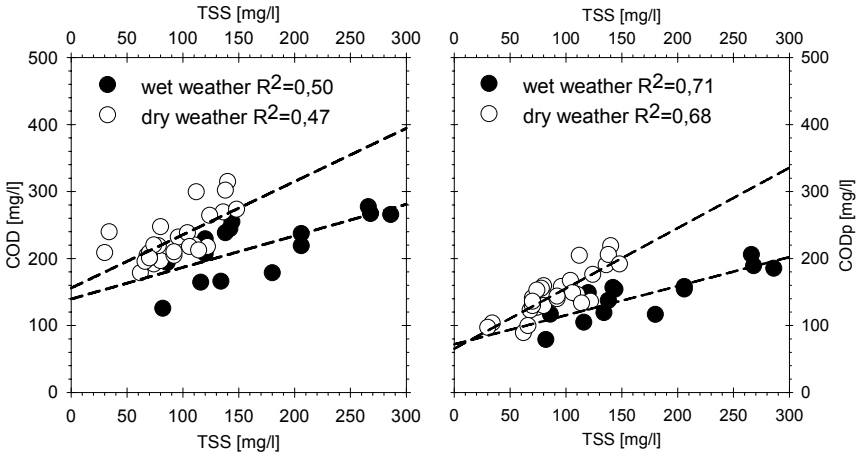

Figure 2 : Relationships between TSS concentration versus total and particulate fraction of COD concentration

An other significant observation is about the f_d index, because its variability suggests the choose of the preferential form of treatment or series of unit operations/processes.

As shown in Table 1, the dissolved COD fraction for all events stayed below 0.5, in particular f_d values dropped during wet weather (approximately 0.3). These relatively low f_d values indicate that the organic mass were predominately in the particular phase.

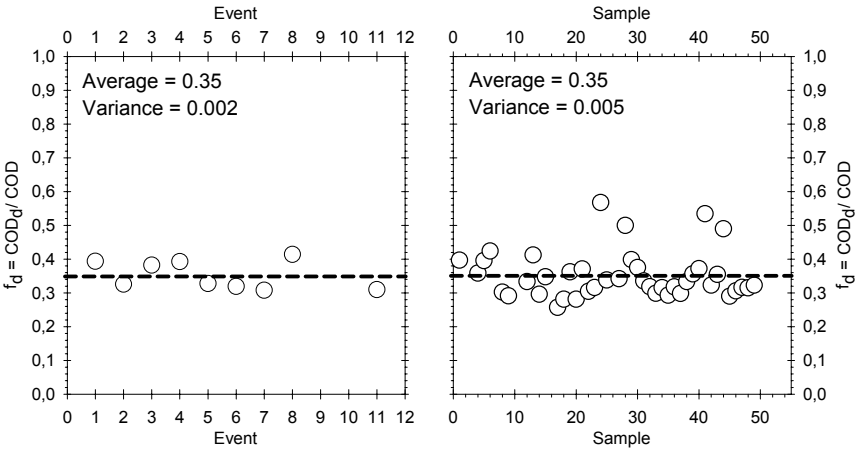

Figure 3 : Variability, of dissolved chemical demand fraction f_d, respectively for every event and for every sample

In addition, as exhibited in Figure 3, in which the f_d was plotted separately as function of events and samples, statistical analysis carried out on the results revealed very low variancy with respect to f_d mean value (0.002 and 0.005 respectively). In fact, the

study shown that f_d values evaluated for the specific experimental site range between 0.3-0.4, remained relatively stable, despite varying characteristics of events.

4 CONCLUSION

Results are utilized to illustrate the need to improve WWTP operations to not only quantity loadings but also to variability of quality loadings between wet and dry weather and during wet weather transport.

The current study placed the emphasis on the different behaviour of organic and inorganic constituents between dry and wet weather. In particular, relationships between TSS and COD for wet and dry weather flow were examined. While the relationships were different for dry and wet weather, each was reasonably linear. Differences are due to differences in partitioning, chemistry (organic vs. inorganic) and differences in hydraulic/hydrologic transport phenomena.

With regards COD fractions, understanding of the partitioning and the speciation of organic loading between and within events is crucial in designing in situ and regional strategies to control these organic loads. In particular, investigations concerning f_d value estimation that are carried out; since such analyses have fundamental implications for control-strategy selection and treatment strategy-alternative design.

Estimation of f_d values for the nine measured events all led to the same conclusion. This study indicates that the f_d values turned out to be very low especially during wet weather and COD_p percentage is generally greater than COD_d, comprising as much as 70% of the total COD. Results generated by this research provide relevant implications with regards to treatment design and they can be used in developing control strategies to remove substantial organic and inorganic loading levels optimizing unit treatment operations/processes. In particular, the results obtained provide the potential to demonstrate that the selection of a treatment strategy that involves a physical unit operation is required. Particulates could be removed through physical mechanisms such as sedimentation and clarification. These treatment units could also provide significant removal of organic loads for the organic fractions that is particulate. Therefore, the data collected basically suggest physico-chemical unit operations that could be capable of removing both organic matter and particulate matter as suspended, settleable and sediment solids.

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